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DISSOLVED ORGANIC MATTER IN SEAWATER AS A SOURCE OF PARTICULATE FOOD[1]

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ABSTRACT

Particulate organic material produced by bubbling air through filtered seawater was fed to cultures of the brine shrimp *Artemia salina* Linnaeus.

Growth rate of *Artemia* fed on organic particles was slower than that of *Artemia* fed on dried yeast. Growth of starved animals was significantly less than particle-fed animals; starved animals were dead by the fifth or eighth day after hatching.

The possible importance of organic particles produced by wave-induced bubbles at sea is discussed.

INTRODUCTION

The apparent discrepancy between the amount of food available in the sea and that required by copepods is a paradox stated by Marshall and Orr (1955) who feel it is unlikely that dissolved organic material as such fills the missing-food gap. A possible source of nutrients for planktonic organisms may be in the particulate organic matter in the ocean, according to Nishizawa and Riley (1962) and to Parsons and Strickland (1962). Sutcliffe, Baylor, and Menzel (1963) have shown that such particles can be formed from dissolved organic material in seawater through the action of rising bubbles. The purpose of this paper is to show that the particulate organic matter so produced can serve as food and can support the growth of a filter-feeding crustacean.

MATERIALS AND METHODS

The brine shrimp, *Artemia salina* Linnaeus, was chosen to test the nutritional possibilities of organic particles despumated from seawater. *Artemia* is an efficient filter feeder which is easily hatched and grown in seawater at room temperature. All seawater used in these experiments was first filtered through a 0.45-μ filter to remove any particulate material. Four cultures of 250 to 500 *Artemia* each were hatched in 1,100 ml of seawater and were maintained at about 23C. The two experimental cultures were fed three times daily, on a 150-ml suspension of organic particles freshly despumated from 2 liters of filtered seawater. The two control or starved cultures were supplied with similar amounts of filtered seawater. The same volumes were removed from each culture before feeding and the fluid was withdrawn through fine bolting cloth to prevent accidental loss of *Artemia*.

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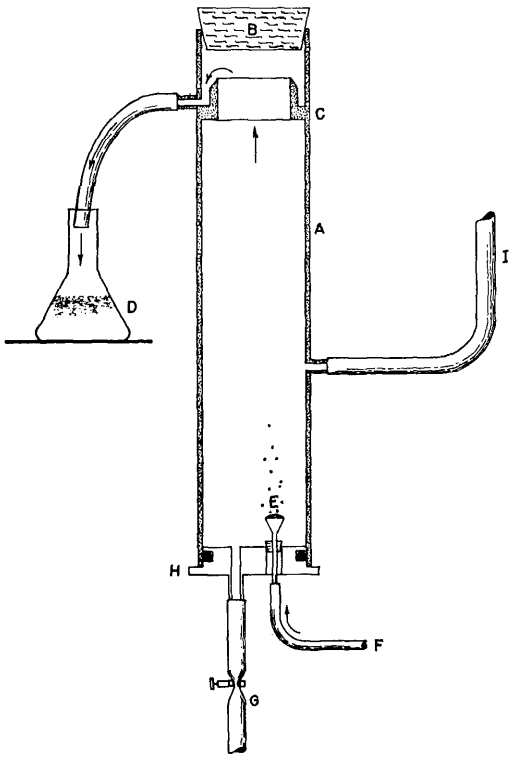

FIG. 1. Foam tower used in bubbling experiments. A. Plastic cylinder. B. Rubber stopper. C. Plastic gutter insert. D. Flask for collecting foam. E. Fritted glass disc. F. Tube to compressed-air supply. G. Foam tower drain. H. Plastic bottom insert fitted with O ring. I. Tube to seawater supply.

Growth of the *Artemia* was estimated from measurements of body length. Samples of *Artemia* from the control and experimental cultures were measured on alternate days starting with the third or fourth days after hatching. Body lengths were measured under a dissecting microscope fitted with an ocular micrometer.

To see whether bacteria were present in quantity in the cultures, microscope slides were prepared from culture fluid samples, were stained, and then examined under oil immersion.

Organic particulate matter to feed the *Artemia* was produced by aerating 2 liters of filtered seawater in the foam tower shown in Fig. 1. Forcing a volume of 280 ml of air per minute through the fine sintered glass filter at the bottom of the foam tower formed a cloud of fine bubbles in the column and resulted in a layer of foam at the surface. The uppermost layer of foam slowly overflowed into the collecting-ring gutter and thence to the collecting flask. Filtered seawater was run into the bottom of the tower to replace that lost from the top.

RESULTS

The data of Figs. 2A and B and Table 1 show the growth curves of *Artemia* fed dried yeast (Sutcliffe, unpublished data), *Artemia* fed suspended particulate matter, and control *Artemia* fed nothing. The *Artemia* fed on organic particles grew as well as those fed on yeast through the fourth day and thereafter increased in size but at a slower rate than yeast-fed animals. The majority of animals in Experiment A had stalked eyes and caudal furcae by the 14th day. The evidence indicates that these carbon-rich aggregated particles provided the major source of nutrition for this crustacean. Growth rates given here for *Artemia* fed on yeast are somewhat less than those of Gilchrist (1960) for cultures fed on marine algae. The slower growth rates on the fourth and following days of particle-fed *Artemia* may reflect a simple lack of food. By feeding time, the culture fluid was clear and showed little particulate matter left in suspension.

Microscopic examinations of the animals showed all observed individuals fed with particles to have food present in the gut; only one specimen of the starved group was found with food in its gut. Cursory examinations of the cultures fed with particles showed few bacteria up to the eighth day. Means of body length and the numbers of specimens examined are given in Table 1. The means of particle-fed and of starved specimens differed significantly from each other at better than the 99.9% level. In the control groups, the fifth and eighth days' sampling exhausted the supply of starved specimens, while the containers of fed animals were still well populated with normal-appearing animals.

Provasoli and Shiraishi (1959) raised *Artemia* on starch particles in a medium

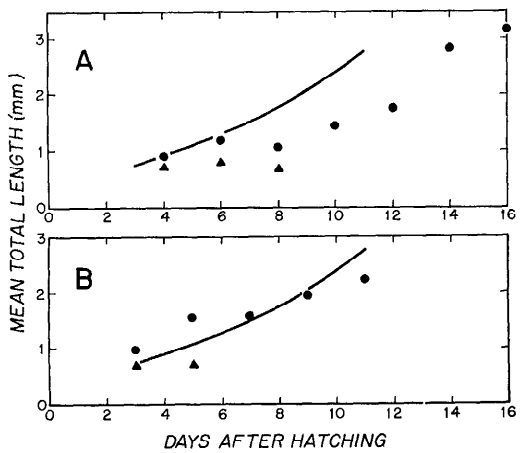

FIG. 2. Results of two *Artemia* growth experiments with different foods. — yeast-fed animals, • • animals fed on organic particles, ▲ ▲ starved animals.

rich in dissolved nutrients. These authors state that the *Artemia*, in swallowing the starch particles, inbibed enough nutrient solution to promote growth; there is also the possibility of adsorption of the nutrients on the starch. In the present case, it is doubted that the organic-particle-fed specimens could swallow enough of the filtered seawater in which they grew to make much difference in their growth rate.

We have used the growth and development of *Artemia* as a preliminary test of whether marine organic particulate material might constitute a satisfactory food for a filter-feeding crustacean. Clearly, the nutritional requirements of *Artemia* may differ from those of marine zooplankton, but it is unlikely that the differences are so great that marine zooplankton cannot utilize particulate organic matter. Therefore, particulate organic material produced by bubbling air through seawater must be considered as a possible if not an important source of food for marine organisms. Further experiments using marine zooplankton are now indicated. Also, the relation between the production of organic particles by wave-induced bubbling and Langmuir circulation needs further investigation, as pointed out by Sutcliffe et al. (1963).

A further possibility exists that large communities of intertidal filter feeders may be supported partly by an abundance of particulate material produced by the foaming action of waves breaking on rocks and beaches.

REFERENCES

GILCHRIST, B. M. 1960. Growth and form of the brine shrimp *Artemia salina* (L). Proc. Zool. Soc. Lond., **134**: 221–235.

MARSHALL, S. M., AND A. P. ORR. 1955. The biology of a marine copepod. Oliver and Boyd. 188 p.

NISHIZAWA, S., AND G. A. RILEY. 1962. Research in particulate materials suspended in sea water. P. 150–152. *In* D. S. Gorsline, [ed.], Proceedings of the First National Coastal and Shallow Water Research Conference. National Science Foundation, Office of Naval Research, Tallahassee, Florida.

PARSONS, T. R., AND J. D. H. STRICKLAND. 1962. Oceanic detritus. Science, **136**: 313–314.

PROVASOLI, L., AND K. SHIRAISHI. 1959. Axenic cultivation of the brine shrimp *Artemia salina*. Biol. Bull., **117**: 347–355.

SUTCLIFFE, W. H., JR., E. R. BAYLOR, AND D. W. MENZEL. 1963. Sea surface chemistry and Langmuir circulation. Deep-Sea Res., **10**: 233–243.

TABLE 1. *Number of specimens measured and mean length in mm*

Culture	Days after hatching											
	3	4	5	6	7	8	9	10	11	12	14	16
Yeast fed	100		200		100		100		100			
	0.74		1.07		1.49		2.06		2.76			
Group A												
Particle fed		14		10		48		15		10	12	10
		0.92		1.18		1.09		1.44		1.76	2.78	3.17
Starved		18		10		9						
		0.73		0.77		0.66						
Group B												
Particle fed	10		10		10		10		10			
	0.98		1.55		1.59		1.94		2.21			
Starved	13		11									
	0.73		0.73									